Advances in Simulation for
Production and Logistics Applications
Markus Rabe (ed.)
Stuttgart, Fraunhofer IRB Verlag 2008

Semantic Web Framework for Modelling and Simulation of Manufacturing Systems

Markus Rabe, Pavel Gocev
Fraunhofer Institut Produktionsanlagen und Konstruktionstechnik (IPK)
Pascalstrasse 8-9, 10587 Berlin, Germany

Abstract. The development of new products and manufacturing systems is usually performed in the form of projects. Frequently, the conduct of the project takes more time than planned due to inconsistency, incompleteness, and redundancy of data for the description of a manufacturing system, which delays other project activities and sometimes influences the start of production (SOP). This paper proposes a semantic Web framework for cooperation and interoperability within product design and manufacturing engineering projects. Data and knowledge within the manufacturing domain are modelled within ontologies applying rule-based mapping. The framework facilitates the generation of new knowledge through rule-based inference that enriches the ontology. This enables a high-level completeness of the model in an early phase of product design and manufacturing system development, which is a basic prerequisite for the realisation of a proper simulation study and analysis. The simulation results can be integrated into the ontologies as a knowledge that additionally extends the ontology.

1 Introduction

The discrete event simulation as a part of the digital factory has a goal of evaluation of the planned and designed manufacturing system. Utilizing various scenarios through variation of particular parameters or modules within the simulation model enables an analysis of different structures and variants of the manufacturing system. The simulation studies always start with the acquisition of data and information about the system to be modelled, involving project members who cooperate and exchange data and information. The design and development activities and project meetings yield new findings and conclusions, which are knowledge applied to a particular situation. Besides the centrally managed data and information within the IT systems like ERP, MES, PLM, etc. additional data sources are kept by the project members for operational purposes and developed as a result of the planning activities. During the project work and through the human interaction and cooperation additional efforts are needed for data exchange, enrichment and especially for synchronisation. Moreover, a very important activity is an elimination of inconsistencies and redundancies, as only complete data and redundancy free information can be used for further analysis and simulation.

In order to reduce the cooperation work and to shorten the time needed to complete modelling of the manufacturing system and therewith the simulation studies, a systematic and explicit description of the manufacturing domain is needed, resulting in a model that can be easily utilised for simulation, supporting the project members in their daily work.

2 Requirements and Functionalities

Generally, there are three base requirements that have to be satisfied for an explicit description and modelling of a manufacturing domain for simulation purposes.

The first one is to deploy an already widely accepted modelling language that can foster the exchange of data and information and support the cooperation and interoperability. A state of the art of meta-languages that are already in deployment within the simulation domain is given by Gocev (2007). The Extended Markup Language (XML) due to its application can be utilised as a base for modelling and exchange of data structures. The second requirement is to use established and widely deployed data models and structures. Here the solution should be searched in already existing or in emerging standards and open standards for modelling of the manufacturing domain, discussed by Gocev (2007), too. Most suitable for this purpose are the Enterprise Control System Integration standards ISA-95 (ISA 2000; ISA 2001; ISA 2005) and the Open Application Group Integration Specification - OAGIS (2008). They define main classes and objects of the manufacturing system that can be used as a skeleton for domain modelling. The third requirement is to enable an explicit description of the manufacturing domain, which facilitates the integration of various sources and therewith the interoperability within the development project. Besides the elimination of the inconsistencies and redundancies of data and information, the explicit description can foster the interoperability between different data sources and IT Systems. Here the solution can be found in deployment of meta-languages that have been developed on the base of XML, enabling inclusion of semantic and logical relations between the objects within the models of a manufacturing system, described by Rabe and Gocev (2008). The necessary level of domain description can be achieved through classes which are organised as taxonomies with assigned individuals (instances) and defined relations between them and logical restrictions in one unified model. These models are called ontologies and can be used to develop a knowledge base for one particular domain under consensus of the involved partners, as a means to collect and structure the existing knowledge as well as the generation of new knowledge through reasoning. The Resource Description Language – RDF (2008) and Web Ontology Language – OWL (2008) can be deployed to develop an ontology of the manufacturing domain in order to gather data and knowledge that describe a particular manufacturing system. Moreover these meta-languages and thereon developed rule languages are the basis for inference and generation of new knowledge based on the existing one within the ontology.

A very extensive overview of ontologies for modelling and simulation in production and logistic is given by Gocev (2007). Most recent and noticeable developments about the application of ontologies in manufacturing domain have been achieved within the Project Pabadis'Promise (2008) where the ontology has to provide a formal and unambiguous description of manufacturing systems based on ISA-95. Another application of ontologies in the manufacturing domain is described by Seog-Chan and Shang-Tae (2007) using the semantic mediation method for mapping different ontologies describing manufacturing systems. The Manufacturing System Engineering (MSE) Ontology is developed by Lin at al. (2004) to support various project teams within the manufacturing projects. The state of the art about ontologies for the manufacturing domain is exposed by Rabe and Gocev (2008), too.

Further benefit from the utilisation of the semantic Web technologies could be the development of models for decision and control logic independent from the simulation models, to solve the problem highlighted by Rabe (2000) that could not be solved with the neutral models.

As a result from the exposed requirements, the following functionalities emerge, that could be enveloped and realised in a semantic Web framework for data and knowledge integration, generation of knowledge and modelling and simulation of manufacturing systems:

- Embedding of domain knowledge within a single knowledge base.
- Inclusion of results from the daily work of project members involved in the design and development of new products and manufacturing systems.
- Discovery of relationships between the entities of the knowledge base.
- Generation of new knowledge through inference.
- Integration of generated knowledge into the knowledge base and therewith enrichment of the knowledge base.
- Facilitating simulation and evaluation of a manufacturing system and integration of simulation results back into the knowledge base.
- Extraction and provision of different views on the manufacturing system structures for the users and project members utilising the knowledge base.

3 Semantic Web Framework for Modelling and Simulation (M&S) in the Manufacturing Domain

The skeleton of the semantic Web framework (figure 1) for explicit description of the manufacturing domain for modelling and simulation is a reference manufacturing ontology (OWL-M). Standard-based structures are modelled in classes, subclasses and relations between them and can be used for the description of any manufacturing system. This ontology can be populated with the instances of one particular manufacturing system, yielding the Manufacturing Knowledge Base (MKB). The knowledge base can include data and information from different project partners providing a basis for simulation.

Usually the dispersed data and information within the developing projects are owned by various project members, resulting in different structures and formats. To enable their inclusion into the MKB a unique format is needed and then a consistent structure is demanded to eliminate the inconsistencies and redundancies. Most of the applications have an exporting function as an XML format. Several XML files, with different structures can be imported in one or more ontologies with structures as in original files different among each other. The process of bringing those ontologies in a structure defined with other ontology is called mediation. In this case the structure is given by OWL-M and the result is the Manufacturing Knowledge Base

Due to the variety of data and information sources, where usually the same objects are described by several people in a different way and very often not completely, the MKB comprises hidden knowledge, that still has to be discovered by the user through manual search. For example, the product designer does not give a statement about the production. The technologist has the knowledge which materials or parts can be processed in which sequence and what kind of resources are needed. Determined rules modelled upon the ontology can be used for inference. The result will be the generated knowledge and therewith an enriched manufacturing knowledge base (MKB). Only complete and unambiguous descriptions and data about the manufacturing system can be used for simulation purposes. The enrichment of the MKB can yield a completion of information needed for simulation of the manufacturing system (bill of materials, production plans, available resources, production orders and shift plans).

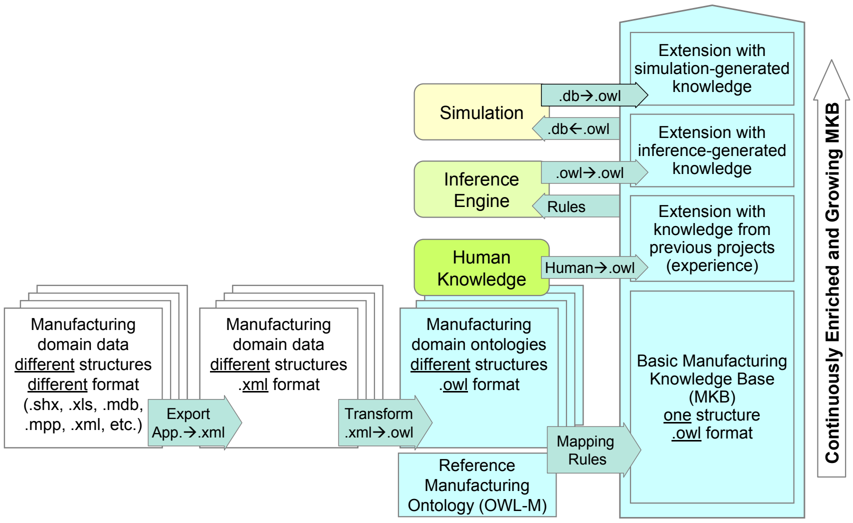

Figure 1: *Semantic Web Framework for M&S of Manufacturing Systems*

3.1 Reference Manufacturing Ontology

The Reference Manufacturing Ontology (OWL-M) (figure 2) is under development at Fraunhofer IPK and is built using the RDF/OWL syntax upon the object models and structures defined within the ISA-95 standard series and the open standard

OAGIS. OWL-M is an extension of the data model for simulation presented by Rabe and Gocev (2006), comprising the main classes from the ISA-95 standard:

- Process segments as a business view of the production,
- Product definition with bill of materials and production plans,
- Resources and their subclasses (personnel, equipment and material),
- Work description of production, maintenance, quality tests and inventory, related to capabilities as the highest sustainable output rate that could be achieved, schedules as the planned activities to be performed and performance as a report of the production responses.

Beside these classes OWL-M includes additional ones for description of shift patterns, spatial elements for the layout, manufacturing engineering project phases (installation, qualification and ramp-up), resource status, queues, transporters and paths, performance indicators, etc.

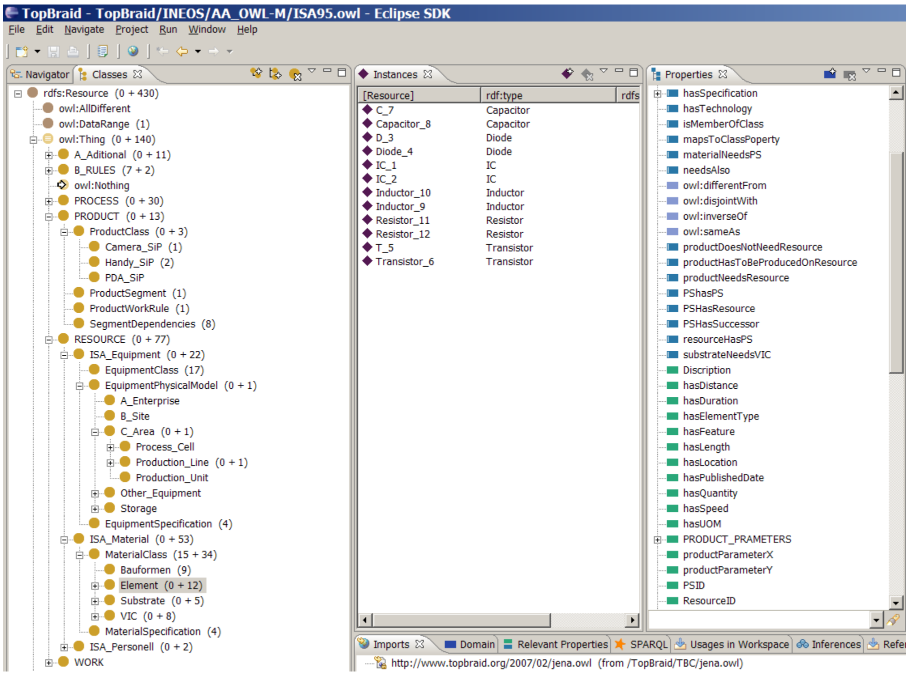

Figure 2: *Reference Manufacturing Ontology (OWL-M) with Example Individuals*

The attributes and parameters as well as the relations between the objects of the manufacturing system can be described with the properties within the ontology through the basic building block, the triple subject-predicate-object.

3.2 Rule-based Mediation of Source Ontologies

The Manufacturing Knowledge Base (MKB) comprises the content from several different sources around the OWL-M. The input information from different IT applications is imported as several XML files. These XML files can be transformed to OWL files with a weak semantic, since they still have the original structure as in the original XML file just using the OWL syntax. The integration of the elements within these input OWL files into the structure of OWL-M can be realised through rule-based mediation. The mapping procedure yields the correspondences between the source OWL files and OWL-M. The alignment and matching of the ontologies are specifications of similarities. Those specifications are the base for rule development by the engineer. The rules govern the merging and creation of the MKB on the skeleton of OWL-M. An inference engine (software) applies the rules, reasons over the OWL-M structure, if necessary generates new classes, properties and instances and populates the existing ones in form of statements (triples).

The results from the mapping are shown in figure 3 on an example of process models developed according to the Integrated Enterprise Modelling (IEM) method specified in Spur et al.(1993) with the tool for business process modelling MO²GO documented by Mertins et al. (2006).

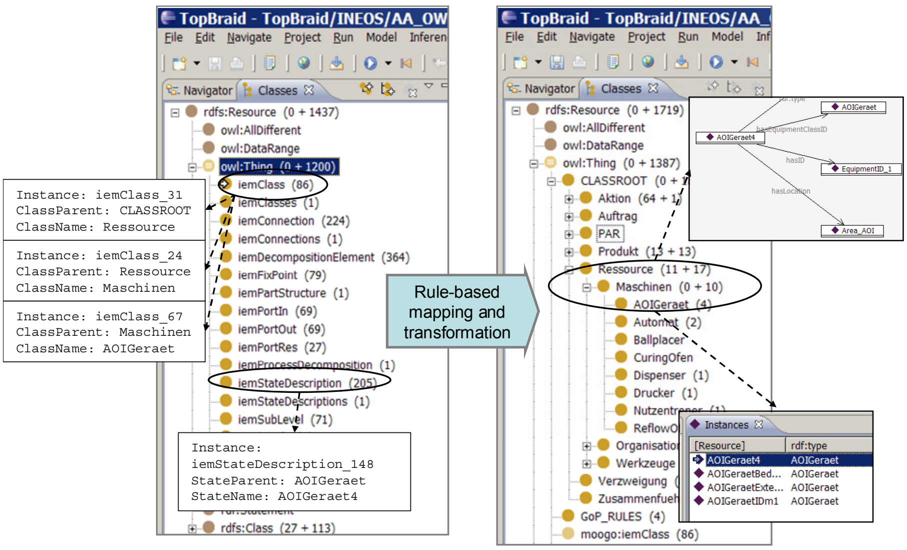

Figure 3: *Rule-based Mapping of Ontologies*

The process model in MO²GO can be exported in a specific XML format. This file can be used for the generation of a weak ontology in OWL format, but still with unchanged structure, shown on the left side of figure 3, where the relations parent-child are expressed with the attributes in XML-style (attributes). Suitable rules serve to map and match the elements from the MO²GO structure into the OWL-M structure, to model the relations parent-child as subclasses in additional levels and to generate individuals of a respective class and relations between them.

All facts that are needed for the further application of the ontology and the knowledge gained as an experience from the previous projects can be integrated into the MKB. The engineer can manually either change the existing classes and individuals, or model new ones. The software tools for ontology modelling offer several possibilities for this step as direct code writing in OWL, or modelling via forms and through graphs.

3.3 Inference and Enrichment of the Manufacturing Knowledge Base

Due to the variety of information sources upon which the MKB is generated, there is a “hidden” knowledge within the MKB that it is still not “visible” for the user. For example, the bill of material given by the product designer frequently does not contain additional materials like consumables in production. The list of fixtures and tools needed for a particular product is not given by the product designer and not available in the product description. The process plan does not exist, too. To bring all these information in a structure needed for further analysis (e.g. bill of resources, process plan), usually time-consuming discussions and information exchange between project members is needed.

This goal of data and information completion can be achieved through rules and reasoning performed again by an inference engine upon the existing knowledge within the MKB. The antecedent part of the rules consists of existing axioms and facts about the individuals (triples) from different classes or ontologies. The consequent part includes the facts and statements that have to be generated through inference. Figure 4 shows an example of one rule written in a Jena notation (Jena 2008) that enables an extension of the bill of material given by the product designer. The facts within the ontology that present the knowledge by other project members (e.g. technologist) can be utilised to extend or even fully complete the bill of material.

```
<R1 rdf:about="http://www.owl-ontologies.com/OWL_M.owl#GoP_RULE_2">
  <jena:rule rdf:datatype="http://www.w3.org/2001/XMLSchema#string">
      [BOM:   (?P :hasMaterial ?C)
              (?C :needsMaterial ?M)
              (?P, ?PP, ?PPV)
              (?M, ?MP, ?MPV)
              (?PP owl:equivalentProperty ?MP)
              equal(?PPV, ?MPV)
              -&gt; (?P, :hasMaterial, ?M)]
  </jena:rule>
</R1>
```

Figure 4: *Example of a Rule for Extension of the Bill of Material*

The first rule atom (*?P :hasMaterial ?C*) considers all products *P* and the instances *C* that are related with *P* through the property *hasMaterial*. The following atoms of the rule’s body are additional premises of the rule. The head of the rule contains just one atom (triple) that defines the form of the generated triples. The rule governs, if all premises given in the antecedent are satisfied for a set of particular individuals, to extend all bills of material that are in relation with the particular product *P* with the property *hasMaterial*. All values for *M* that satisfy the conditions will be added to the list and therewith the MKB will be augmented.

The same procedure can be applied considering other knowledge within the MKB through the deployment of suitable rules that are specified to reach a particular goal. Deploying the knowledge of the production engineer, a process plan can be generated, consisting alternative resources or technologies. The results are to be seen after the inference as triples (subject-predicate-object). Only those triples that are selected by the user build the generated knowledge and can be asserted into the MKB.

The MKB can be also continuously extended and fed by the users with the manual entry of knowledge usually coming of the experts' experience, of some not integrated sources like pictures, discussions with the partners or other experts, observations, conclusions or agreements. This can be performed as modelling new classes, properties, instances and restrictions within the existing MKB.

3.4 Utilisation of the Manufacturing Knowledge Base for Simulation

The enrichment of the MKB can yield a completion of information needed for simulation of the manufacturing system (bill of materials, production plans, available resources, production orders and shift plans). The more data about the manufacturing system are available, the more accurate and closer to reality the simulation can be performed. The missing information in the MKB related to the simulation can be entered manually as triples in order to prepare a basis for a simulation with particular software. The triples from the MKB through transformation as spreadsheet can be used as an input for the simulation model, where the values in the first column are subjects, predicates are head of the other columns and the values within the table are the objects.

After the end of the simulation, the results (e.g. throughput time, resource utilisation, buffer time and needed capacities) can be imported into the MKB through XML-to-OWL transformation. Therewith the information and knowledge gained from the simulation can be assigned and stored in the MKB to the related individuals and classes. This knowledge can be used further for inference and enrichment of the MKB. Different simulation scenarios can be stored into the MKB and related performance indicators of the manufacturing system gained from the simulation experiments will be assigned and related to the scenarios. This enables an inclusion of the simulation-based generated knowledge about the behaviour of the manufacturing system under certain (predefined) conditions that are typical for each scenario. The whole knowledge of the scenarios structured within the MKB serves for further developments of the framework towards the intelligent advisors that should answer some questions during the planning and design of manufacturing systems.

4 Conclusions and Future Developments

An ontology for the manufacturing domain is needed as a skeleton for the modelling of the knowledge about a particular manufacturing system. The basis for the core manufacturing ontology (OWL-M) that is presented in this paper is taken from the structures and the object models defined within the ISA-95 series and open standard OAGIS.

The distributed information about one particular manufacturing system can be transferred from the source files into several ontologies. The objects of those ontologies can be integrated into the OWL-M skeleton through rule-based ontology mediation, yielding the Manufacturing Knowledge Base (MKB) for a particular manufacturing system. Rules can generate new knowledge and through assertion of inference statements the MKB can be augmented.

Since this paper describes a method and first applications, further developments are necessary in order to provide the users with a more friendly interface for ontology modelling, as it could not be expected that the project members are familiar with ontology modelling software. Emerging technologies for development of semantic wiki can be utilised for this purpose.

Further developments can result in rule-based modelling of decision logic and its decoupling from the simulation model. Therewith the changes of the decision logic can be performed easily as the logic will not be encoded into the specific simulation language.

The utmost goal for coupling the MKB and simulation would be an automated generation of simulation models directly from the ontology. Bringing together manufacturing and simulation domains (ontologies) can foster the generation of simulation models from the MKB of one particular manufacturing system.

The described semantic Web framework can substitute a part of the project activities usually in form of data and information exchange, understanding, agreeing, reasoning and knowledge generation. The modelling of the manufacturing domain with ontologies facilitates and accelerates the cooperation and collaboration processes within the projects of product design and development of manufacturing systems.

References

Gocev, P. (2007) Semantic Web technologies for simulation in production and logistic – A survey. Simulation und Visualisierung 2007 – Doktorandenforum Diskrete Simulation, University Magdeburg, pp. 1-10

ISA (2000) Enterprise-Control System Integration, Part 1: Models and Terminology. Instrument, Systems and Automation Society, Research Triangle Park (NC), www.isa.org (visited 20.04.2008)

ISA (2001) Enterprise-Control System Integration, Part 2: Model Object Attributes. Instrument, Systems and Automation Society, Research Triangle Park (NC), www.isa.org (visited 20.04.2008)

ISA (2005) Enterprise-Control System Integration, Part 3: Models of Manufacturing Operations Management. Instrument, Systems and Automation Society, Research Triangle Park (NC), www.isa.org (visited 20.04.2008)

Jena (2008) Jena – A Semantic Web Framework for Java. SourceForge Inc., Mountain View (CA), http://jena.sourceforge.net (visited 20.03.2008)

Lin, H.-K.; Harding, J.A.; Shahbaz, M. (2004) Manufacturing system engineering ontology for semantic interoperability across extended project teams. International Journal of Production Research 42 (2004) 24, S. 5099-5118

Mertins, K.; Jaekel, F-W (2006) MO²GO: User Oriented Enterprise, Models for Organizational and IT Solutions. In Bernus, P., Mertins, K., Schmidt, G. (eds.). Handbook on Architectures of Information Systems, 2nd Ed. Springer, Berlin Heidelberg New York, pp. 649-663

OAGI (2008) Open Applications Group Integration Specification. Version 9.2. Open Applications Group, www.oagi.org (visited 18.02.2008)

OWL (2008) Web Ontology Language. World Wide Web Consortium, Cambrige (MA), www.w3.org/2004/OWL (visited 18.02.2008)

Pabadis'Promise (2008) PABADIS (Plant automation based on distribution systems) based product oriented manufacturing systems for re-configurable enterprises. University of Magdeburg, www.pabadis-promise.org (visited 18.02.2008)

Rabe, M. (2000) Future of Simulation in production and logistics: Facts and visions. In: Mertins, K.; Rabe, M. (eds.): The New Simulation in Production and Logistics. Fraunhofer IPK, Berlin, pp. 21-43

Rabe, M., Gocev, P. (2006) Simulation models for factory planning through connection of ERP and MES systems. In: Wenzel, S. (ed.) Simulation in Produktion und Logistik 2006. SCS Publishing House, Erlangen, pp. 223-232

Rabe, M., Gocev, P. (2008) Semantic Web framework for rule-based generation of knowledge and simulation of manufacturing systems. In: Mertins, K.; Ruggaber, R.; Popplewell, K.; Xu, Xiaofei (eds.): Enterprise Interoperability III: New Challenges and Industrial Approaches. Springer, London, S. 397-409

RDF (2008) Resource Description Framework. World Wide Web Consortium, Cambridge (MA), www.w3.org/RDF (visited 18.02.2008)

Seog-Chan, O.; Shang-Tae, Y. (2007) Manufacturing interoperability using a semantic mediation. International Journal of Advanced Manufacturing Technology. Online Article, DOI 10.1007/s00170-007-1198-2. Springer, London

Spur, G., Mertins, K., Jochem R. (1993) Integrierte Unternehmensmodellierung. Entwicklungen zur Normung von CIM. Beuth, Berlin, Wien, Zürich